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Review

The worldwide research trends on water ecosystem services

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ABSTRACT

In recent decades, the scarcity of water resources, the deterioration of aquatic ecosystems and associated repercussions for other ecosystems have become major global challenges. In this context, research on water ecosystem services has become increasingly important. The objective of this work is to analyse the evolution of this line of research worldwide for the period 1998–2017. A bibliometric analysis showed that this line of research has been gaining relevance within the ecosystem services field. Exponential growth has been observed in such research, and more than 65% of the studies have been performed in the last five years. Economic analyses have little relevance and gradually have lost relative importance. Results show that the most used keywords during the studied period are Ecosystem, Biodiversity, Water Quality, Ecology and Climate Change. The highest contributing countries on this topic are USA, China, UK, Germany and Australia. The leading institutions in this research field are the Chinese Academy of Sciences, the Research Center for Eco-Environmental Sciences and the Wageningen University and Research Centre. A high level of international collaboration is observed between the different agents involved in ecosystem services research and extensive cooperation networks. Three differentiated clusters have been detected around which this type of work is grouped: aquatic ecosystems, forest ecosystems and agricultural ecosystems. The interactions between different types of ecosystems must be investigated with respect to water, and holistic frameworks should be developed that integrate the different disciplines to achieve a more complete analysis of the set of services that contribute to the sustainable management of the different types of ecosystems.

1. Introduction

Water is a structuring element that acts as both as a service linked to different types of ecosystems as irrigation for agroecosystems, protection for coastal and marine ecosystems (Caro et al., 2018), water supply for forests, and a support for other services in aquatic ecosystems for example, food provision, carbon sequestration or habitat for species (Guo and Xu, 2019). In this way, water is an irreplaceable and fundamental element for life, either in the form of habitat as a support for an aquatic ecosystem or through a set of services provided by other ecosystems, of which water is their foundation (Díaz et al., 2018). Therefore, water plays an essential role in the development of human society because of its dependence on the services provided by ecosystems (Pedro-Monzonís et al., 2015; Montoya et al., 2016; Val et al., 2016; Liu et al., 2017a; Manju and Sagar, 2017). The extension of wetland ecosystems is estimated at more than 1280 million hectares (MEA, 2005). These ecosystems together with forests are considered the most valuable in terms of biodiversity (Vihervaara et al., 2010; Saeed and Sun, 2017; Alamgir et al., 2018). The degradation and loss of aquatic ecosystems and their biodiversity is occurring faster compared with that of any other ecosystem (Paredes et al., 2019) because of multiple factors, such as population growth, changes in land use, agricultural and urban expansion (Feng et al., 2018), and overexploitation as a result of economic development (Martín-López et al., 2016; Flávio et al., 2017; Liu et al., 2017; Zhang et al., 2017). Among the predicted effects of global climate change are alterations of long-term droughts and imbalances in the water supply (Mitrică et al., 2017). As a consequence, both wetlands and other ecosystems that depend on water are suffering a great impact that may be irreparable (Chitsaz and Azarnivand, 2017; Mitrică et al., 2017). In this way, human well-being decreases further, especially for the poorest populations of the lowest-income countries and regions with arid climates (Kotta et al., 2009; Damkjaer and Taylor, 2017).

Water contributes directly or indirectly to the provision of a wide

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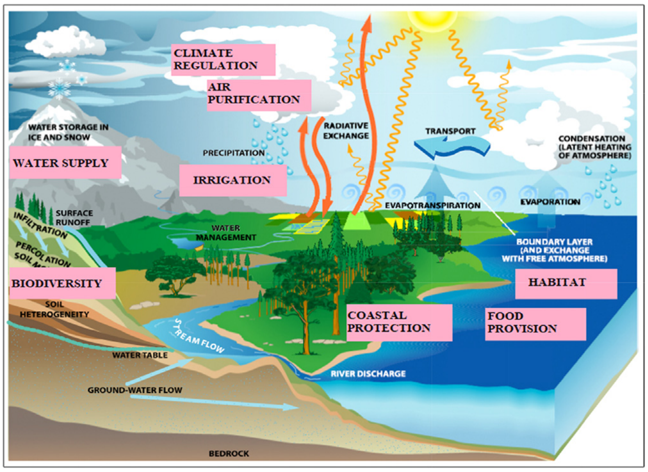

Fig. 1. Water cycle and water ecosystem services across different ecosystem types.

range of services that support human well-being, such as the production of food and raw materials, water supply and purification, nutrient retention, carbon sequestration, the protection of biodiversity, climate regulation, coastal and flood protection, recreational opportunities and tourism (Wang et al., 2011; Landuyt et al., 2014; Martín-López et al., 2016; Flávio et al., 2017). In parallel to the degradation and overexploitation of aquatic ecosystems, an increased demand for many of these services is expected, which implies greater water deficits, suggesting scarcity and limited access to water becoming significant challenges for society as well as imposing structural limitations for economic development (Lavrnić et al., 2017; Liu et al., 2017b; Suárez-Almiñana et al., 2017). According to a United Nations 2015 report on the development of global water resources, a 40% drinking water scarcity will be observed worldwide by 2030 (WWAP, 2015). Thus, a lack of water has become a key and pressing problem that affects the whole global system (Wang et al., 2011; Bekchanov et al., 2017; Damkjaer and Taylor, 2017; Liu et al., 2017a). Fig. 1 illustrates the water cycle and the service flow across different ecosystem types.

Ecosystem services are all those contributions, direct or indirect, from ecosystems to human well-being (Clemente et al., 2019). These services can be grouped into four categories: provisioning, regulating, cultural and supporting services. Provisioning services refer to all those economic activities linked to goods provided by the ecosystem. Regulating services are the indirect benefits provided by the environment. Cultural services are immaterial in nature and are the result of experiences with the natural environment. Supporting services are those that serve as support for the supply of the other categories (Tian et al., 2015). The concept of ecosystem services has evolved over decades to become a new paradigm. The Ecosystem Services Framework is a recent approach whose origin can be associated with several works published in the 1990s (Costanza et al., 2017). In 1997, a book was published by Gretchen Daily entitled *Nature's services: societal dependence on natural ecosystems* (Daily, 1997), and it included definitions, history, economic assessment, services and case studies. In the same year, an assessment of global ecosystem services was published in the journal *Nature* (Costanza et al., 1997).

Initiatives, such as the Millennium Ecosystem Assessment (MEA) project in 2005, The Economics of Ecosystems and Biodiversity (TEEB) in 2010, and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2011, have assumed new momentum that have positioned the concept of ecosystem services as policy tools to achieve the sustainable use of natural resources (Seppelt et al., 2011). The objective of the Millennium Ecosystem Assessment was to provide useful knowledge for policies, strategies and ecosystem management to interested parties (Nieto-Romero et al., 2014) and represented a turning point in the consolidation of the Ecosystem Services Framework (Vihervaara et al., 2010). Regions characterized by high vulnerability to the provision of ecosystem services and human well-being require information on trends in all aspects of ecosystem service flows, including the impact of governance interventions and social and ecological pressures (Geijzendorffer et al., 2017). The theoretical framework of ecosystem services has great potential for supporting informed decision-making through the generation of evidence-based knowledge, which thus contributes to the challenge of ensuring sustainability (Nieto-Romero et al., 2014; Anzaldua et al., 2018; Saarikoski et al., 2018).

In this context, considerable research has been performed on ecosystem services linked to water. This abundant literature raises the need to carry out studies to quantitatively and analytically synthesize research findings and offer useful information about its status and future trends. In this sense, Vihervaara et al. (2010) state that there are gaps and needs for research on ecosystems and their specific services. Quantitative analyses can help highlight these shortcomings in specific issues. Bibliometric reviews have been published on various topics related to ecosystem services and water that include general trends in research (Vihervaara et al., 2010; McDonough et al., 2017; Costanza et al., 2017), forest ecosystems (Aznar-Sánchez et al., 2018a), agroecosystems (Tancoigne et al., 2014), drinking water research (Fu et al., 2013), and lead in drinking water (Hu et al., 2010), among others. However, to our knowledge, such analyses have not been performed in relation to ecosystem services linked to water.

This study aims to bridge this knowledge gap by exploring the dynamics of the development of this line of research. The main objective is to quantitatively analyse the evolution of water ecosystem services globally for the period 1998–2017 and assess the relative importance of water-focused studies in the investigation of ecosystem services. To achieve this objective, a bibliometric analysis will be carried out. The results of this type of analysis are useful for identifying the most outstanding lines of research, the main drivers and future research trends within a subject, both for new and senior researchers (Zhang et al., 2017). How this line of research evolves and the new tendencies it leads to can be very useful for agencies, private research centres and governmental institutions interested in subjects related to the environment and the sustainable management of natural resources, especially in regard to developing strategies and identifying key collaborators (Hassan et al., 2014).

2. Methodology

2.1. Bibliometric analysis

The bibliometric analysis method was introduced by Garfield in the mid-20th century (Huang et al., 2014) and aims to identify, organize and analyse the main components within a specific research area (De la Cruz-Lovera et al., 2017). Since its inception, this methodology has been extended to multiple disciplines such as biology, engineering, administration, ecology and medicine (Garrido-Cárdenas and Manzano-Agugliaro, 2017). The bibliometric method combines mathematical tools and statistics, allowing to analyse the trends of a research topic, identify the main drivers (Li and Zhao, 2015; Cui, 2018) and the relevance of their publications (Giménez et al., 2018). In the bibliometric analysis, three types of indicators defined by Durieux and Gevenois (2010) can be distinguished: quantity, importance and structural. The quantity indicators show the volume of published works and the productivity of authors, journals and institutions in a field. Importance indicators show the impact of publications. Some of the most used indicators are the number of citations, the H index and the journal classifications. The structural indicators analyse the existence of networks in a research field. In addition to these three indicators, there are different approaches in bibliometric analyses. The co-occurrence, co-citations and coupling analyses are among the traditional approaches.

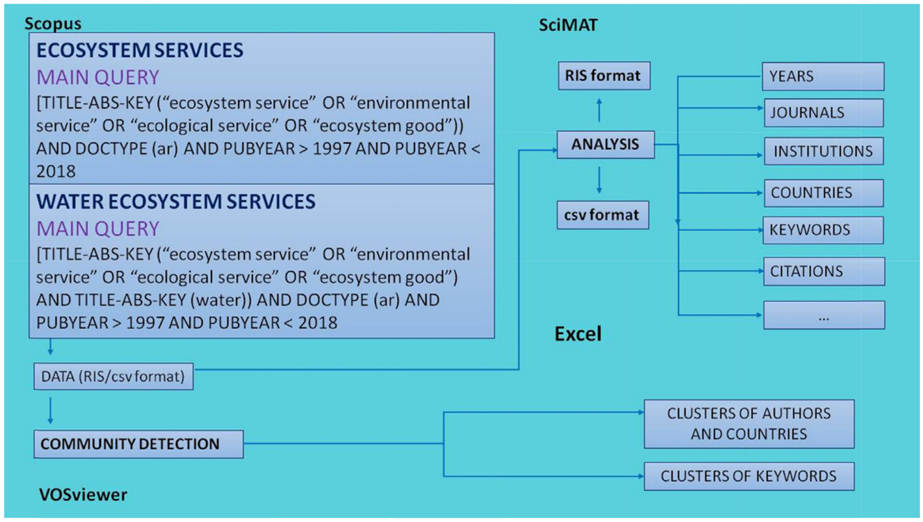

Fig. 2. Methodology.

This methodology has evolved by developing analysis frameworks to evaluate innovation (Robinson et al., 2013), techniques for overlaying maps and associating variables (Rafols et al., 2010), visualization tools through text extraction and data extraction (Zhang et al., 2017), and tool development based on routine types of automated software (Suominen and Toivanen, 2016; Montoya et al., 2018).

In our study, a traditional approach based on co-occurrence has been used. For the development of the analysis, productivity, quality and structural indicators have been included (Aznar-Sánchez et al., 2018b). First, agents with the highest number of publications are identified. These agents include authors, institutions, countries and journals. Second, the impact of the publications of these agents is analysed. This analysis, especially in relation to journals, is of great interest to researchers because it represents a method of assessing the relevance of the journal in which to publish their work (Malesios and Arabatzis, 2012; Garrido-Cárdenas et al., 2018). The selected indicators are the citation count, the H index and the SCImago Journal Rank impact factor. The H index is defined by the total h of N documents with at least h citations each, while the other (N-h) articles have h citations each; that is to say, the H index for an author or a country is the number h of documents between an author or the number of publications of a country (Np) that have at least h citations each (Padilla et al., 2018). The SJR measures the weighted citations received by the journal, where the weighting of citations depends on the field of study and the prestige of the cited journal. Third, we use mapping techniques to analyse the network structure between the different agents.

2.2. Data processing

The step prior to the selection of the sample works is the selection of the database. The two most commonly used databases in bibliometric analyses are Scopus and Web of Science (WoS). However, depending on the objectives of the study, one may be more appropriate than the other. Mongeon and Paul-Hus (2016) indicate that Scopus has a greater number of indexed journals than WoS. According to the results of Gavel and Iselid (2008), although only 54% of Scopus publications are included in the WoS, 84% of the WoS titles can be found in Scopus. McDonough et al. (2017) state that the Scopus database is the most representative in the subject of ecosystem services compared to WoS, CAB Abstracts and Environmental Sciences and Pollution Management (published by ProQuest). Therefore, the use of the Scopus database allows us to ensure the selection of a representative sample of works. In addition, Scopus is easily accessible, allows the visualization and analysis of the data, and the download of these in different formats (Aleixandre-Benavent et al., 2018), which enables its subsequent treatment with software applications (Velasco-Muñoz et al., 2018a, Salmeron-Manzano and Manzano-Agugliaro, 2018). Based on all these considerations, Scopus was selected to extract the sample of works for our analysis.

The terms for the search were selected based on previous work by Vihervaara et al. (2010), Tancoigne et al. (2014), McDonough et al. (2017), Costanza et al. (2017) and Aznar-Sánchez et al. (2018a). These parameters were used for searching the abstract, keywords and titles of related aforementioned works. The concept of ecosystem services has evolved over the last decades with the development of the Ecosystem Services Framework. In the process of selecting the sample, the main terms associated with this framework have been used. The study period selected from 1998 to 2017 immediately follows the publication of what is considered the origin of the Ecosystem Services Framework (Daily, 1997; Constanza et al., 1997) and the most developed work on the subject. Only documents until 2017 were included to facilitate comparisons to complete annual periods. To avoid duplicities in the results and given the less rigorous evaluation process of other types of documents, only original articles have been included in the sample (Cossarini et al., 2014). A different search query may lead to different results. Such a search was performed in February 2018, and the sample of this study was composed of 4815 articles. Additionally, a general search was performed of articles on ecosystem services with the same restrictions, to analyse the relative importance of water in ecosystem services research. Fig. 2 shows the searches carried out and the methodology applied in our research work.

The analysed variables were the number of publications per year, author, affiliation institution, country, subject area, name of the publication, and keywords. After downloading this information in RIS and CSV formats, the first task was the elimination of duplicates. Both the name of an author and that of an institution can be found in different formats in different documents, which can lead to errors when examining these records. Therefore, these two variables were analysed and the different records were regrouped so that the same author and institution were not counted more than once. Once all the information was refined, the different tables and figures were prepared for the correct visualization and analysis of the data. The programs used were Excel (version 2016) and SciMAT (v1.1.04). The VOSviewer tool is widely used for the preparation of network maps (Velasco-Muñoz et al., 2018b) and was chosen for the development of this work. Finally, the keyword analysis was used to extract the main research areas related to water ecosystem services. A regrouping of terms was used to eliminate duplications due to plurals, hyphens, uppercase words, etc.

Table 1
Major characteristics of WES articles from 1988 to 2017.

Year	A	AU	AU/A	NR	NR/A	TC	CTC/CA	J	C
1998	5	11	2.20	160	32	18	3.60	5	2
1999	16	41	2.56	584	37	51	3.29	14	6
2000	25	49	1.96	753	30	62	2.85	21	11
2001	19	58	3.05	745	39	113	3.75	18	11
2002	26	71	2.73	1025	39	166	4.51	25	10
2003	24	76	3.17	776	32	272	5.93	18	11
2004	28	103	3.68	1028	37	266	6.63	27	17
2005	47	193	4.11	1461	31	406	7.13	38	24
2006	83	260	3.13	2896	35	608	7.19	67	33
2007	100	305	3.05	3485	35	963	7.84	72	31
2008	127	415	3.27	5342	42	1220	8.29	96	37
2009	188	702	3.73	7567	40	1890	8.77	129	50
2010	257	1073	4.18	12,814	50	2968	9.53	157	61
2011	327	1404	4.29	14,485	44	3877	10.13	172	72
2012	378	1512	4.00	18,651	49	5558	11.17	216	69
2013	472	2006	4.25	23,170	49	8319	12.61	217	65
2014	579	2516	4.35	27,826	48	10,521	13.80	265	81
2015	578	2588	4.48	28,186	49	13,143	15.38	260	82
2016	754	3401	4.51	37,434	50	15,712	16.40	331	92
2017	782	3467	4.43	38,584	49	18,244	17.52	321	93

A: number of total articles; AU: the annual number of authors; NR: the number of references in total articles; TC: the annual number of citations in total articles; CTC/CA: annual total citation per cumulative number of publications; J: the annual number of journals; and C: the annual number of countries.

3. Results and discussion

3.1. Evolution of scientific production

Table 1 shows the evolution of the main characteristics of the research on water ecosystem services (WES) published in 1998–2017. The number of articles has followed an upward trend that has increased dramatically in recent years. Thus, in the last five years of the analysis period (2013–2017), more than 65% of the total articles are concentrated. In this way, this line of research has been gaining interest from its origin until exponential growth was achieved starting in the year 2007. Fig. 3 shows the growth trend in the number of WES articles. It also highlights some of the main milestones in the development of the ecosystem services framework. Fig. 4 presents the comparative evolution of the number of articles on ecosystem services (ES) and on WES. To homogenize the time series, logarithms have been applied to the data. Based on the calculation for 1998, the average annual growth rate of ES articles is 24.4% while that of WES articles is 30.5%. These data indicate that issues related to water are becoming increasingly important in the investigation of ecosystem services. This result is consistent with that obtained by Vihervaara et al. (2010) and McDonough et al. (2017) in their work on trends in ecosystem services research. Following the same procedure as in Fig. 4, Fig. 5 shows the evolution of the main variables in Table 1.

Table 1 also summarizes other indicators of interest to show the dynamics of WES publications. During the entire period, the 4815 articles analysed have accumulated 84,377 citations, which means an average of 17.52 citations per article. The number of countries participating in this line of research has increased from 2 in 1998 to 93 in 2017, which indicates that WES research has reached an increasingly global dimension. The number of journals in which WES articles have been published has increased from 5 in 1998 to 321 in 2017, which shows the wide range of journals in which the analysed WES articles are hosted. The average number of authors per article has doubled from 2.20 in 1998 to 4.43 in 2017. And the number of references included in WES articles has also grown significantly, increasing on average from 32 in 1998 to 49 in 2017.

3.2. Distribution of production in subject areas and journals

Fig. 6 shows the evolution of the main subject areas in which WES articles are grouped according to the Scopus classification (note that a single article can be indexed in more than one category). During almost the entire period, the category of Environmental Sciences accounts for the largest number of published works with 71.9% of the total, and it is followed by Agricultural and Biological Sciences with 47.8%, Social Sciences with 17.4%, Earth and Planetary Sciences with 12.8%, and Biochemistry, Genetics and Molecular Biology with 5.1% of the total articles. The remaining categories do not reach 5% of the articles analysed. The first three categories are also the most important in research on ecosystem services (McDonough et al., 2017) and forest ecosystem services (Aznar-Sánchez et al., 2018a).

Economic Sciences have been linked to the study of ecosystem services from their very beginning, mainly through value assessment studies for decision-making processes (Costanza et al., 2017). At the beginning of the period, the Economics, Econometrics and Finance category accounted for approximately 15% of the articles. However, this category has been gradually losing importance, and in 2017, it only

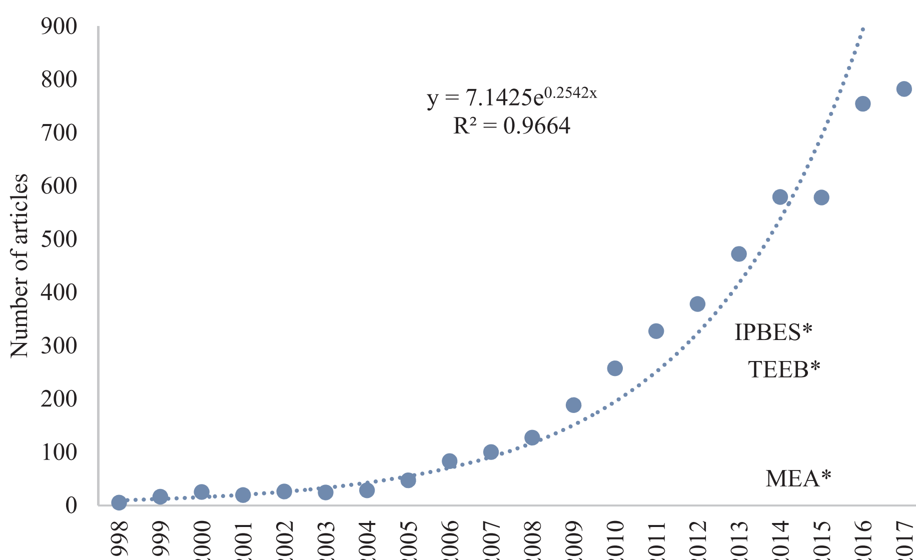

Fig. 3. Annual number of articles from 1998 to 2017. *IPBES: Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services; TEEB: the Economics of Ecosystems and Biodiversity; MEA: Millennium Ecosystem Assessment.

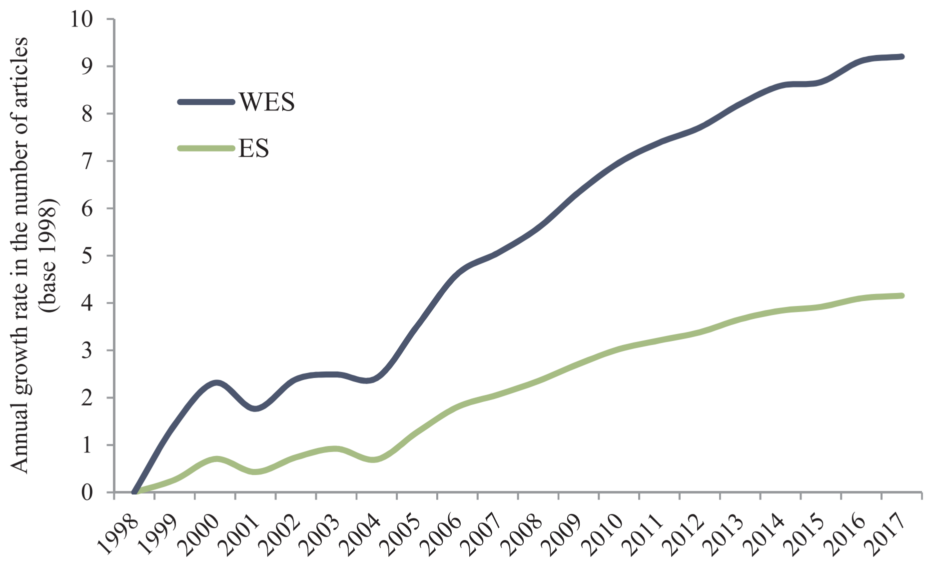

Fig. 4. Comparative trends in the research fields of ecosystem services (ES) and water ecosystem services (WES) from 1998 to 2017.

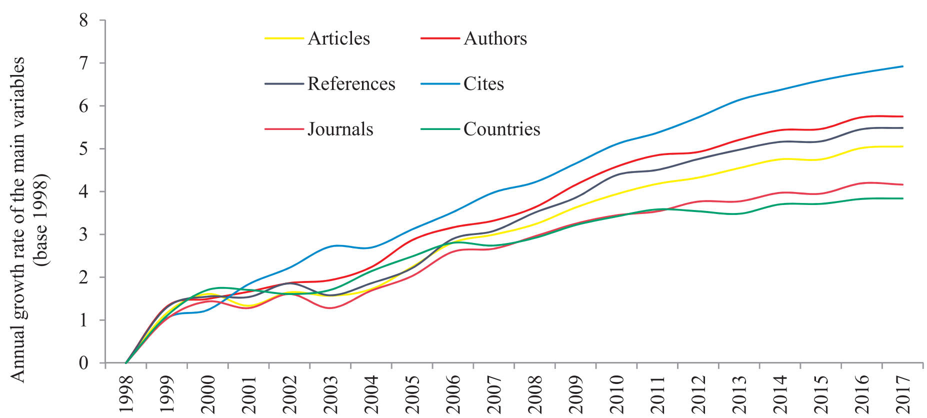

Fig. 5. Trends of the main characteristics of articles on WES research from 1998 to 2017.

represented 1.6% of WES articles published. The decline in the Economics, Econometrics and Finance category is largely due to more studies using participatory socio-cultural methods that are considered to be better at capturing a wider range of the value dimensions of the set of services provided by ecosystems (Chan et al., 2012; Nieto-Romero et al., 2014; Quintas-Soriano et al., 2016a, 2016b; Costanza et al., 2017). While the Economics, Econometrics and Finance category is less relevant in WES research, this category occupies fourth and third place in ecosystem services and forest ecosystem services studies, respectively (McDonough et al., 2017; Aznar-Sánchez et al., 2018a), which indicates less development of economic research in WES studies relative to the other ecosystem services.

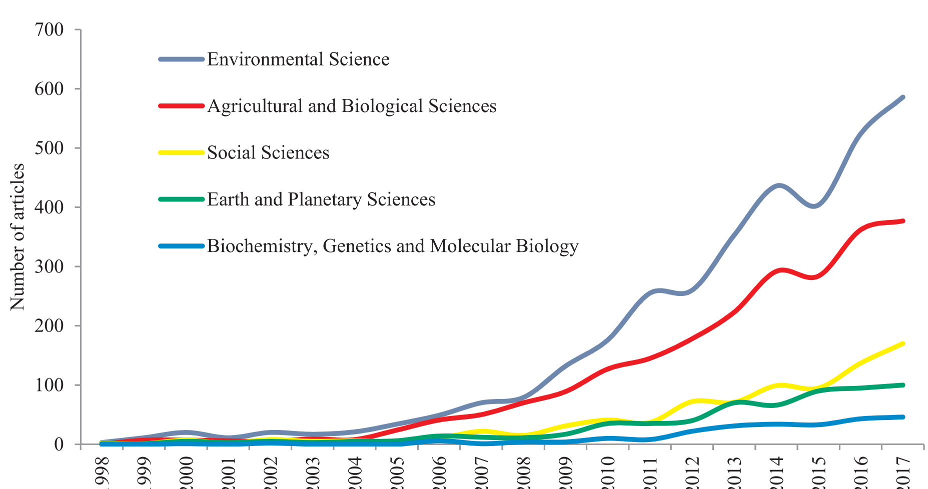

Fig. 6. Comparisons of the growth trends of subject areas in WES from 1998 to 2017.

Table 2
Mean relationship between the most relevant subject areas in WES from 1998 to 2017.

Main subject area	A	1998–2002			2003–2007			2008–2012			2013–2017		
		R (A)	Subject area	%	R (A)	Subject area	%	R (A)	Subject area	%	R (A)	Subject area	%
Environmental Science	3460	1 (65)	Social Sciences	26.15	1 (191)	Agricultural and Biological Sciences	48.17	1 (901)	Agricultural and Biological Sciences	40.73	1 (2303)	Agricultural and Biological Sciences	42.94
			Agricultural and Biological Sciences	23.08		Social Sciences	14.66		Social Sciences	16.76		Social Sciences	20.41
			Economics, Econometrics and Finance	15.38		Economics, Econometrics and Finance	7.33		Earth and Planetary Sciences	8.32		Earth and Planetary Sciences	10.42
Agricultural and Biological Sciences	2303	2 (25)	Environmental Science	60.00	2 (132)	Environmental Science	69.70	2 (608)	Environmental Science	60.36	2 (1538)	Environmental Science	64.30
			Earth and Planetary Sciences	16.00		Social Sciences	13.64		Earth and Planetary Sciences	9.54		Social Sciences	14.95
			Biochemistry, Genetics and Molecular Biology	12.00		Earth and Planetary Sciences	6.82		Social Sciences	6.91		Earth and Planetary Sciences	10.86
Social Sciences	836	3 (20)	Environmental Science	85.00	4 (47)	Environmental Science	59.57	3 (196)	Environmental Science	77.04	3 (573)	Environmental Science	82.02
			Economics, Econometrics and Finance	15.00		Agricultural and Biological Sciences	38.30		Agricultural and Biological Sciences	21.43		Agricultural and Biological Sciences	40.14
			Agricultural and Biological Sciences	10.00		Earth and Planetary Sciences	17.02		Earth and Planetary Sciences	10.71		Earth and Planetary Sciences	8.73

A: number of total articles; R(A): R = ranking position; A = number of total of articles; %: percentage of articles on the main subject area.

The publications corresponding to the categories of Multidisciplinary and Decision Sciences represent 2.3% and 1.8% of the total articles for the entire period, respectively. However, these categories may not be truly representative of the actual multidisciplinary publications on WES. Ecosystem services are by nature a multidisciplinary concept and exhaustive analysis requires collaboration between numerous disciplines. Thus, the study of ecosystem services inherently combines the natural and social sciences, which represents a phenomenon that is not easily represented by the categorizations of subject areas (McDonough et al., 2017). Table 2 shows the evolution of the links between the three main subject categories in which WES work is classified. The close relationship between the Social and Environmental Sciences is observed for research in this area, while Economic Sciences lose importance with respect to the three main categories.

Table 3 shows the 10 journals with the highest number of WES publications in the period 1998–2017. The journal with the largest number of articles is Acta Ecologica Sinica. This journal has led the ranking of articles published since 2008, although it is the journal with the lowest SJR index of the whole group and the lowest average number of citations per article. The journals that have published the most articles have been Science of the Total Environment and Plos One, which very high-quality indices, being Q1 in their respective categories. The journal with the highest SJR index is Ecosystem Services. This journal occupies the fourth position with 100 published articles despite being the most recent with regard to this topic given that its first article dates from 2012. The creation of this journal is considered one of the milestones in the development of research on ecosystem services (Costanza et al., 2017). Since its inception in 2012, this journal has managed to position itself in a short time in the top positions of the ranking in terms of number of articles published despite the existence of top-level consolidated journals with which it shares this subject. Ecological Economics is the journal that has the highest average number of citations per article with 61.6, and it is followed by Plos One with 24.1 and Ecological Engineering with 15.3. The Ecosystem Services, Acta Ecologica Sinica and Plos One journals are also among the five most productive journals in ecosystem services (McDonough et al., 2017; Costanza et al., 2017) and forest ecosystem services (Aznar-Sánchez et al., 2018a).

3.3. Countries, institutions and authors

Table 4 shows the characteristics of WES articles of the 10 countries with the most publications during the period 1998–2017. The USA is the country with the largest number of articles published on WES. During the entire period, it has accumulated a total of 1641 articles, which represents 34% of the total sample. The country with the second-highest number of articles published is China, with a total of 950, representing 19.7% of the total. Next would be the United Kingdom, with 538 articles (11.2% of the world total), Germany, with 397 (8.3%), and Australia, with 351 (7.3%). This list of the ten most productive countries in WES is consistent with that suggested by McDonough et al. (2017) and similar to that of Zhang et al. (2016) because it only differs in two countries (Sweden and Italy). With respect to the articles on forest ecosystem services, the consistency is also very high because the only difference is the appearance of Brazil (Aznar-Sánchez et al., 2018a).

To isolate the influence of country size on the volume of published articles, the number of articles per capita measured as the number of articles per million inhabitants (APC) has been calculated. Based on this variable, Australia is the most productive country, with 14.51 articles per million inhabitants, followed by the Netherlands, with 12.98, the United Kingdom, with 8.21, Canada, with 6.42, and the USA, with 5.08. Canada is the country with the highest average citations per article, with 46.5, followed by Spain, with 41.9, the Netherlands, with 35.8, France, with 35.7, and Australia, with 33.5. In the study by Zhang et al. (2016) the Netherlands is the country with the highest number of

Table 3
Ten most active journals by number of articles in WES from 1998 to 2017.

Journal	A	SJR*	JCR*	H	C	TC	TC/A	1st A	R (A)			
									1998–2002	2003–2007	2008–2012	2013–2017
Shengtai Xuebao Acta Ecologica Sinica	202	0.180 (Q4)	ND	11	China	579	2.9	2007	0	9(4)	1(68)	1(130)
Science Of The Total Environment	125	1.546 (Q1)	4.610 (Q1)	26	Netherlands	1634	13.1	2007	0	42(1)	13(13)	2(111)
Plos One	114	1.164 (Q1)	2.766 (Q1)	30	USA	2752	24.1	2008	0	0	5(20)	4(94)
Ecosystem Services	100	1.743 (Q1)	4.395 (Q1)	18	Netherlands	1110	11.1	2012	0	0	120(2)	3(98)
Ecological Engineering	93	1.042 (Q1)	3.023 (Q2)	22	Netherlands	1419	15.3	2000	5(2)	21(2)	10(14)	5(75)
Ecological Economics	81	1.657 (Q1)	3.895 (Q1)	34	Netherlands	4991	61.6	1999	1(7)	1(13)	2(35)	16(26)
Ecological Indicators	81	1.406 (Q1)	3.983 (Q1)	19	Netherlands	1014	12.5	2009	0	0	37(6)	5(75)
Journal Of Environmental Management	74	1.161 (Q1)	4.005 (Q1)	20	USA	1114	15.1	2003	0	21(2)	6(19)	7(53)
Chinese Journal Of Applied Ecology	63	0.235 (Q3)	ND	13	China	544	8.6	1999	2(4)	2(10)	4(22)	15(27)
Environmental Management	58	0.921(Q1)	2.177 (Q2)	15	Germany	597	10.3	2002	13(1)	4(7)	13(13)	10(37)

A: number of total articles; SJR: Scopus Journal Rank year 2017; JCR: Journal Citation Report year 2017; C: country; TC: Total citation; TC/A: average number of cites by article; R(A): R = ranking position; and A = number of total of articles. *In order to select the quartile, the category Environmental Sciences has been chosen for all journals, except for *Plos One.* Agricultural and Biological Sciences categories have been used in the SJR and the Multidisciplinary category in the JCR

Table 4
Most productive countries of WES from 1998 to 2017.

Country	A	APC	TC	TC/A	H index*	R (A)			
						1998–2002	2003–2007	2008–2012	2013–2017
USA	1641	5.08	46,948	28.6	100	1(46)	1(108)	1(409)	1(1078)
China	950	0.69	10,005	10.5	41	3(6)	2(72)	2(253)	2(619)
United Kingdom	538	8.21	14,825	27.6	59	3(6)	3(17)	3(144)	3(371)
Germany	397	4.81	8599	21.7	48	0	6(11)	5(94)	4(292)
Australia	351	14.51	11,764	33.5	50	9(3)	8(10)	4(114)	5(224)
Canada	233	6.43	10,843	46.5	42	6(4)	5(12)	6(59)	9(158)
France	227	3.39	8093	35.7	38	0	23(2)	7(52)	6(173)
Netherlands	221	12.98	7903	35.8	47	5(5)	6(11)	7(52)	10(153)
Spain	220	4.73	9224	41.9	43	0	15(3)	9(49)	8(168)
Italy	205	3.38	5982	29.2	33	0	15(3)	12(33)	7(169)

* Only sample items. A: number of total articles; APC: number of articles per 1 million inhabitants; TC: annual number of citations for all articles; TC/A: number of citations by article; R(A): R = ranking position; and A = number of total of articles.

citations per article, followed by Sweden, Canada and the USA. In the case of forest ecosystem services, the countries with the highest number of citations per article are Spain, Canada, Australia, France and the USA (Aznar-Sánchez et al., 2018a).

Table 5 shows the main characteristics of the articles of each country via international collaboration. The countries with the highest percentage international collaboration are the Netherlands, Spain, Italy, France and Canada. The USA is the country with the largest network of collaborations, with a total of 96 different collaborators. In addition, the USA is the main contributor to seven of them (China, the United Kingdom, Germany, Australia, Canada, France and Spain). After the USA, the countries with the largest network of international collaborations are the United Kingdom, with 81 collaborators, Germany, with 77, France, with 76, the Netherlands, with 75, and Australia, with 72. These data highlight the global nature of the research in this subject area, with very high collaboration rates and extensive collaboration networks worldwide. The table shows that articles produced through international collaboration obtain a higher average number of citations in all countries. These articles have obtained an average of 39.9 citations compared to 14.5 articles published without international collaboration. Canada, Spain and France are the countries with the biggest difference in the number of citations between articles published with and without international collaboration.

Table 5
International collaboration between countries on WES research from 1998 to 2017.

Country	IC (%)	NC	Main collaborators	TC/A	
				IC	NIC
USA	37.72	96	China, UK, Australia, Canada, Germany	37.7	23.1
China	22.74	60	USA, Australia, Canada, Germany, UK	26.9	5.7
United Kingdom	63.94	81	USA, Germany, France, Australia, Spain	32.6	18.7
Germany	65.99	77	USA, UK, France, Netherlands, Italy	25.7	13.8
Australia	59.54	72	USA, UK, China, France, Canada	43.1	19.4
Canada	69.96	64	USA, UK, Australia, China, Germany	60.6	13.7
France	73.13	76	USA, Germany, UK, Italy, Spain	45.5	8.9
Netherlands	81.00	75	Germany, USA, UK, Sweden, Italy	39.2	21.0
Spain	76.82	61	USA, UK, France, Germany, Italy	50.8	12.5
Italy	73.17	62	Germany, USA, France, UK, Netherlands	36.9	8.1

IC: international collaborations; NC: total number of international collaborators; TC/A: total citations per article; and NIC: no international collaborations.

Fig. 7 shows a collaboration network among countries, where the size of the circle represents the number of articles per country and the colour corresponds to the cluster formed by the different countries. Four clusters can be differentiated in terms of the number of articles: the USA, China, the United Kingdom and Germany. The first cluster (green) links the USA, Australia and Spain mainly with different countries of the American continent. In the second cluster (yellow), the main relationships are established among China, Canada, Japan and South Korea. The third cluster (blue) is composed of the United Kingdom, Belgium, South Africa, India and Kenya, among others. The fourth cluster (red) is composed of Germany, the remaining European countries and Turkey.

Table 6 shows the ranking of the ten institutions with the highest

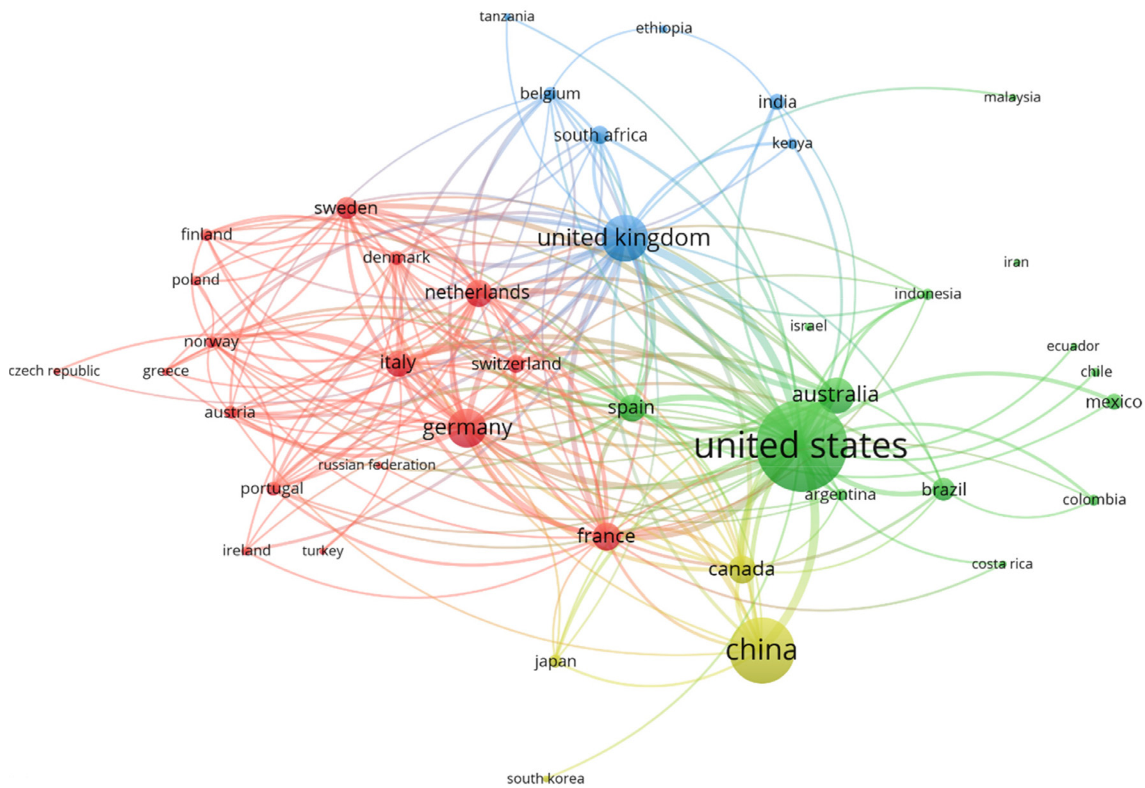

Fig. 7. Cooperation based on co-authorship between countries.

number of WES articles in the period 1998–2017. All institutions except two are located in China and the USA. The Chinese Academy of Sciences occupies the first position, with a total of 374 articles, and in 2002, it ranked first in the number of articles published on this subject and since then it has consolidated its leadership, increasing the distance with respect to the rest of the institutions, which is followed by the Research Center for Eco-Environmental Sciences, with 138 articles, the Wageningen University and Research Centre and the United States Geological Survey, with 95, and Beijing Normal University, with 91. The highest average number of citations per article is held by Stanford University, with 91.09, followed by the United States Geological Survey, with 50.26, and the Wageningen University and Research Centre, with 37.91. The four Chinese institutions account for 13.9% of total articles published on WES during the period analysed but only accumulate 7.9% of the total citations, whereas the four American institutions accumulate 6.5% of published articles and 17.2% of total citations. Six of these ten institutions are also highlighted in other previous works. The USDA Forest Service, the Chinese Academy of Science, Wageningen University, the Centre National de la Recherche Scientifique and the United States Geological Survey are among the institutions with the largest number of publications on ecosystem services during the period 1991–2014 (Zhang et al., 2016). The Chinese Academy of Sciences, the Research Center for Eco-Environmental Sciences and the USDA Forest Service are among the most productive institutions in the publication of forest ecosystem services articles (Aznar-Sánchez et al., 2018a).

With regard to the international collaboration of the institutions, European centres have the highest percentage of work carried out jointly with foreign centres. The institution with the highest percentage of foreign collaboration is the Wageningen University and Research Centre (Netherlands), and 82.11% of its publications are developed with international cooperation. This centre is followed by the CNRS Centre National de la Recherche Scientifique (France), with 75%, and Stanford University (USA), with 56.52%. All institutions obtain a higher

Table 6
Ranking of the top ten institutions of WES from 1998 to 2017.

Institution	C	A	TC	TC/A	H index*	IC (%)	TC/A	
							IC	NIC
Chinese Academy of Sciences	China	374	3901	10.43	31	21.93	18.3	8.2
Research Center for Eco-Environmental Sciences	China	138	1627	11.79	21	18.84	24.8	8.8
Wageningen University and Research Centre	Netherlands	95	3601	37.91	31	82.11	41.8	20.2
United States Geological Survey	USA	95	4775	50.26	25	24.21	148.6	18.8
Beijing Normal University	China	91	660	7.25	15	26.37	11.3	5.8
United States Environmental Protection Agency	USA	82	1288	15.71	20	19.51	21.4	14.3
Stanford University	USA	69	6285	91.09	30	56.52	97.6	82.7
USDA Forest Service	USA	68	2142	31.50	22	30.88	65.3	16.4
Institute of Geographical Sciences and Natural Resources Research	China	66	451	6.83	14	16.67	9.2	6.4
CNRS Centre National de la Recherche Scientifique	France	64	2477	38.70	20	75.00	47.6	12.1

* Only sample items. C: country; A: number of total articles; TC: number of citations in total articles; TC/A: number of citations by article; IC: international collaborations; and NIC: no international collaborations.

Table 7
Ranking of the top ten authors of WES from 1998 to 2017.

Author	A	TC	TC/A	H index*	C	Affiliation	1st A	Last A
Ouyang, Zhiyun	43	520	12.1	15	China	Research Center for Eco-Environmental Sciences	2004	2017
Zheng, Hua	27	384	14.2	14	China	Research Center for Eco-Environmental Sciences	2005	2017
Fu, Bojie	21	484	23.0	10	China	Research Center for Eco-Environmental Sciences	2010	2017
Polásky, Stephen A.	19	1407	74.1	14	USA	University of Minnesota Twin Cities	2007	2017
Acuña, Vicenç	16	357	22.3	13	Spain	Institut Catala de Recerca de l'Aigua	2012	2017
Jiang, Bo	16	163	10.2	6	China	Chang Jiang Water Resources Commission	2010	2017
Everard, Mark	15	97	6.5	6	UK	University of the West of England	2008	2017
Martín-López, Berta	15	328	21.9	12	Germany	Leuphana Universitat Luneburg	2011	2017
Lal, Rattan	14	560	40.0	9	USA	Ohio State University	2007	2016
Lü, Yihe	14	400	28.6	7	China	Research Center for Eco-Environmental Sciences	2010	2017

* Only sample items. A: number of total articles; TC: number of citations in total articles; TC/A: number of cites by article; and C: country.

average number of citations in the articles produced through international collaboration, see column IC compared with column NIC in Table 6. Thus, articles published jointly with foreign institutions obtain an average of 48.6 citations, whereas the average of the remaining articles is 19.4 citations. The case of the United States Geological Survey is remarkable in that it has accumulated an average of 148.6 citations for its collaborative articles compared to 18.8 citations for articles without international collaboration.

Table 7 shows the 10 authors with the highest number of WES publications. All authors have published more than 10 articles, and the oldest was published in 2004. Some of these authors, such as Everard, Fu, Polásky or Ouyang, have extensive research experience, whereas others, such as Jiang, Acuña or Martín-López, have started their research more recently. All these authors continue to maintain this line of research because they have all published WES articles in the year 2017 with the exception of Rattan Lal.

The author with the highest number of publications is Zhiyun Ouyang from the Research Center for Eco-Environmental Sciences of the Chinese Academy of Sciences, with 43 articles. This author has 520 accumulated citations, an H index of 15 in those publications and an average of 12.1 citations per article. The researcher who accumulates the highest number of articles as the first author is Mark Everard, with 12. This author has the least number of citations in the ranking (97), an H index of 6, and is affiliated with the University of the West England. Vicenç Acuña, affiliated with the Catalan Institute for Water Research (ICRA) of the Universitat de Girona, is the newest researcher, given that his first publication is 2012. Even so, he occupies the fifth position in terms of the number of articles published and has accumulated 357 citations in the 16 articles published, being the first author in three of them. The author accumulating the largest number of citations is Stephen A. Polásky, with a total of 1407. This researcher, who is affiliated with the University of Minnesota Twin Cities, has published 19 articles and has an H index of 14. The authors with the highest average number of citations per article are Polásky, with 74.1, Lal, with 40, and Lü, with 28.6.

Fig. 8 shows the collaboration network among authors, where the colour corresponds to the cluster formed by the different authors. From the results obtained, the set with a greater number of relations and at least 5 articles is shown. The figure shows a main nucleus formed by different clusters that unites fundamentally Chinese authors, with almost all affiliated to the Chinese Academy of Sciences. Among them include Ouyang, Zheng, Fu, Lal, Bai and Jiang. A series of groups has different European and American authors, including the cluster that includes Daily, Polasky and Acuña; a cluster with Le Maitre, Richardson, Grizzeti, Egoh and Seppelt among others; and a cluster with Martín-López, Tappeiner, Montes and García-Llorente. Everard does not appear in the graph because none of his co-authors has 5 articles within the selected sample.

3.4. Keyword analysis

A keyword study was carried out to analyse the trends of WES research (Li and Zhao, 2015). After regrouping the terms that appeared in the 4815 articles of the sample, a total of 20,911 different keywords were obtained. The frequency of occurrence of the keywords used in WES research conforms to the distribution of the Power Law. This result coincides with that found in other studies (Li et al., 2008; Wang et al., 2011; Wang et al., 2013) such that a small group of words appears with a high frequency in most of the articles analysed while the bulk of the words used appears in a few or even in a single article. Thus, 13,637 keywords (65.2%) appeared in a single article; 19,444 keywords (92.9%) were repeated in less than 10 articles; only 1467 words (7.0%) were used at least 10 times; and 114 (0.5%) were used at least 100 times.

The keyword analysis reveals that 58.19% of the empirical studies were carried out on aquatic ecosystems (wetlands, coastal and marine, and groundwater), 24.88% in agricultural ecosystems and 16.92% in forests. In addition, 48.96% analysed more than one type of ecosystem jointly. Of the list of the 10 most prolific countries, the country that has been the most frequent object of study is the USA, followed by China, the United Kingdom, Australia, Canada and Spain. These data are consistent with the study by Seppelt et al. (2011), who in their review of studies on ecosystem services concluded that the USA and China are the two countries with the highest number of case studies. The most analysed ecosystem service has been water quality, e.g. surface water quality (Beutel et al., 2016) or wastewater (Bhatia et al., 2017), followed by water supply, habitat for species, carbon sequestration and food provision. In addition, a high number of studies are related to the conservation of biodiversity (Wang, 2017).

The 20 most frequently used keywords, which represent the research hot spots, are shown in Table 8. The analysed period has been subdivided into five-year sub-periods to better show the dynamics. The terms used as search parameters for the selection of the articles in the sample were not included in the analysis. During this period, the 20 main keywords appeared 10,578 times; thus, they can be used to provide an overview of research trends during the period 1998–2017 (Li and Zhao, 2015). The most common word is Ecosystem, which appears in 34.1% of the articles. The main ecosystem types that appear are Wetlands, Forests, Agroecosystems and Rivers. Ecology is the dominant discipline in these studies. The factors of change most studied are Climate change and Land-Use-Change. Most studies use Monitoring as a methodology, they are carried out at the watershed level and the most analysed services are Water-Quality and Water-Supply. Among the main topics are Biodiversity, Environmental-Protection, Water-Management, Conservation-of-Natural-Resources, Sustainability and Sustainable-Development. Fig. 9 shows the evolution of the ten most used keywords in WES during the period 2008–2017.

The temporal evolution of the keywords revealed interesting terminology preferences. Ecosystem services research between 1998 and 2002 is influenced by publications that will later become key

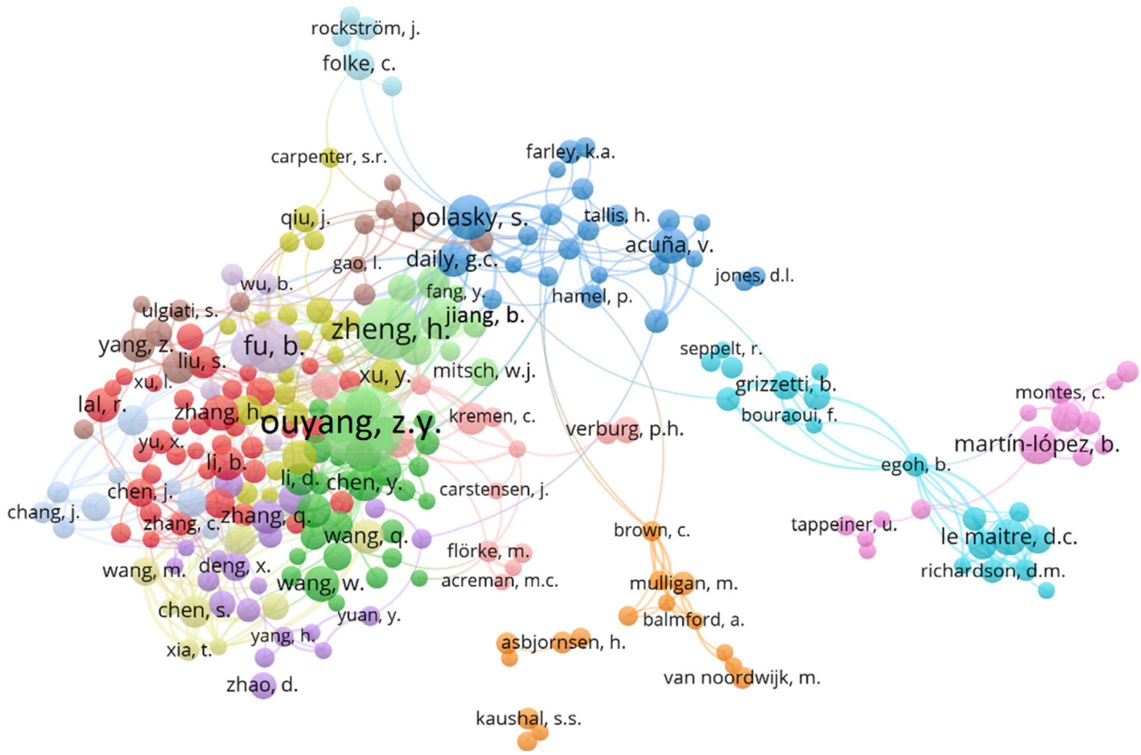

Fig. 8. Cooperation based on co-authorship between authors.

milestones in this subject. The works of Daily (1997) and Costanza et al. (1997) gave rise to numerous studies, especially on the value assessment of services. Wetland was the most analysed ecosystem, with no other ecosystem type appearing among the main keywords. In addition to Water Quality and Water Supply, the term Fresh-Water is used, which disappears in the following subperiods. Ecology, Economics and Hydrology are highlighted. Regarding the methodology, economic analysis is the most important. Regarding factors of change, the focus is on land use. In this period the main topics are Biodiversity (which will be maintained throughout the period analysed), ecosystem function and management, impacts and environmental protection, sustainable development and wastewater-treatment. The 2003–2007 period is mainly

Table 8
Top 20 most used keywords in WES from 1998 to 2017.

1998–2017		1998–2002		2003–2007		2008–2012		2013–2017	
Keyword	%	Keyword	%	Keyword	%	Keyword	%	Keyword	%
Ecosystem	34.1	Ecosystem	25.3	Ecosystem	26.6	Ecosystem	30.2	Ecosystem	36.6
Biodiversity	15.7	Fresh-Water	11.0	Biodiversity	12.8	Biodiversity	18.6	Ecology	18.3
Water-Quality	14.4	Water-Management	11.0	Environmental-Protection	12.1	Water-Quality	15.5	Biodiversity	15.0
Ecology	14.1	Water-Quality	11.0	Water-Quality	11.0	Climate-Change	13.9	Water-Quality	14.3
Climate-Change	13.0	Water-Resource	11.0	Land-Use	10.3	Wetland	11.9	Climate-Change	13.7
Land-Use	11.9	Biodiversity	9.9	Conservation-Of-Natural-Resources	9.6	Water-Supply	11.8	Land-Use	12.4
Environmental-Protection	10.7	Environmental-Protection	9.9	Water-Supply	9.6	Land-Use	11.7	Environmental-Protection	10.9
Wetland	10.6	Watershed	9.9	Ecology	9.2	Water-Management	10.2	Water-Management	10.5
Water-Management	10.3	Ecological-Economics	8.8	Water-Management	8.5	Environmental-Protection	9.9	Wetland	10.5
Water-Supply	9.7	Ecology	8.8	Watershed	7.8	Land-Use-Change	9.5	Water-Supply	8.9
Watershed	8.5	Ecosystem-Management	8.8	Environmental-Impact	7.4	Watershed	9.2	Forestry	8.3
Land-Use-Change	8.3	Water-Supply	8.8	River	7.1	Conservation-Of-Natural-Resources	8.1	Land-Use-Change	8.2
Conservation-Of-Natural-Resources	8.1	Environmental-Impact	7.7	Sustainability	7.1	Sustainable-Development	8.1	Watershed	8.2
Water-Resources	7.8	Wetland	7.7	Forestry	6.7	Water-Resource	7.8	Conservation-Of-Natural-Resources	8.2
Forestry	7.7	Economic-Analysis	6.6	Land-Use-Change	6.7	Carbon-Sequestration	7.4	Agriculture	7.7
Sustainable-Development	7.6	Ecosystem-Function	6.6	Water-Resource	6.7	Ecosystem-Function	7.1	Water-Resources	7.7
Agriculture	7.2	Sustainable-Development	6.6	Wetland	6.7	Forestry	7.0	Sustainable-Development	7.7
River	6.8	Hydrology	5.5	Cost-Benefit-Analysis	6.4	Environmental-Monitoring	6.7	River	7.2
Environmental-Monitoring	6.7	Land-Use	5.5	Agriculture	6.0	Environmental-Economics	6.3	Decision-Making	7.0
Sustainability	6.4	Wastewater-Treatment	5.5	Economics	6.0	Agriculture	6.2	Environmental-Monitoring	6.8

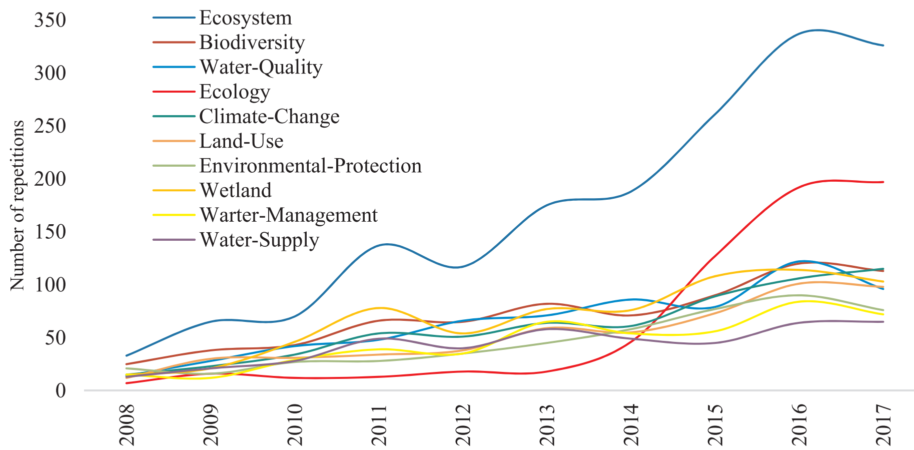

Fig. 9. Evolution of the top ten keywords in WES from 2008 to 2017.

influenced by the Ecosystems and Human Well-being project. This project was another great driver for research in this area. In this sub-period, the study of water services linked to non-aquatic ecosystems, such as forestry and agriculture, as well as wetlands and rivers is notable. Hydrology loses presence, while the disciplines of Economics and Ecology predominate. In terms of methods, the Cost-Benefit analysis is common.

In the period 2008–2012, The Economics of Ecosystems and Biodiversity (TEEB) project of 2010 and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) of 2011 stand out. The first is an international initiative that placed emphasis on services provided by ecosystems and biodiversity and the need for assessing their value, and its objective was to stop environmental degradation and integrate the scientific, economic and political spheres for the adoption of protective measures. The second is an independent intergovernmental body created to strengthen the relationship between science and politics in the area of biodiversity and ecosystem services, and its purpose is to ensure the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development. The highlight in this five-year period is the appearance of different issues related to climate change and its consequences. The effects of increasing temperature in aquatic ecosystems and water scarcity in other ecosystems are analysed in relation to services such as Water Supply, Water Quality and Carbon Sequestration.

The 2013–2017 period saw the largest number of articles published as well as the highest number of repetitions of the main keywords. The fundamental difference with respect to previous years is the domain of Ecology with respect to other disciplines. The hydrological and economic concepts disappear from the top ten of the most used keywords, and the term Decision Making appears for the first time.

Fig. 10 shows the co-occurrence network among the most important keywords. Words with the highest number of links have been considered. They should have been used 50 times at least. The most popular terms are those that appear in larger circles. These terms are those that appear in Table 8. The figure shows the links between terms considered hotspots in this research area and distinguishes three main groups. Based on these hotspots, we name each group with an appropriate theme. The first theme (blue) is mainly dedicated to aquatic ecosystems. Terms such as Aquatic Ecosystem, Coastal Zone, Coral Reef, Estuary, Freshwater Ecosystem, Lakes, Mangrove and Wetlands appear. This theme focuses on change drivers derived from climate change (Climate Change, Climate Effects, Global Change, Global Warming, Greenhouse Gas). Chemistry is the dominant discipline, and the primary countries include developed countries of Europe, North America and Australia (USA, Australia, Europe, United Kingdom, Canada and Spain). The second theme (green) focuses on forest ecosystems (Agroforestry, Forestry, Forest Ecosystem, Forest Cover). This cluster is predominantly economic and concentrates on value assessments of services methodologies, such as mapping, remote sensing or willingness to pay. Sustainability and biodiversity, together with soil uses and their evolution, are the central axes. Asia and Africa are the geographic areas of reference, although countries such as Brazil and Germany as well as China are included. The third theme (red) targets agricultural ecosystems (Agriculture, Agricultural Ecosystem, Agricultural Production), and it includes issues related to crop productivity and adaptation as well as related to soils such as fertility, moisture, conservation, erosion and quality. As far as water is concerned, this cluster focuses on the management of water resources. The main service is food production. Ecology and Hydrology are the dominant disciplines.

4. Conclusions

In this work, we have shown the evolution of WES research over the last 20 years. This topic has a relatively recent origin but has been gaining increasing interest in recent years. An exponential increase in the number of articles published has been observed, and this increase is expected to continue during the next few years. Our results have revealed that water research is gaining relevance in the study of ecosystem services, both in reference to aquatic ecosystems and agricultural and forestry systems.

The three subject areas most linked to WES research are Environmental Sciences, Agronomic and Biological Sciences and Social Sciences. During the last decade, Economic Sciences have been losing importance in WES research. The keyword analysis has reflected how traditional economic methods used in value assessment studies have been displaced by sociocultural methods capable of capturing a broader range of value dimensions. Given the global nature of the factors involved in the management of water resources, the level of international collaboration among the different actors involved in such research has followed an increasing trend.

A community analysis was applied to WES research, and then three different clusters of studies were found, although they were related to each other. The first one is dedicated to aquatic ecosystems and their relationship with climate change. The second is dedicated to forest ecosystems focused on sustainability and biodiversity. The third is focused on agricultural ecosystems with topics related to agronomy and soil conservation.

The keyword study has shown that most studies analyse water as a service in relation to a single type of ecosystem. Because water supports the provision of services, the interactions between different types of ecosystems in relation to water must be studied. Given the intrinsically multidisciplinary nature of ecosystem services, the different value dimensions they contain and their dependence on the concept of social demand, holistic frameworks must be developed that unite the different

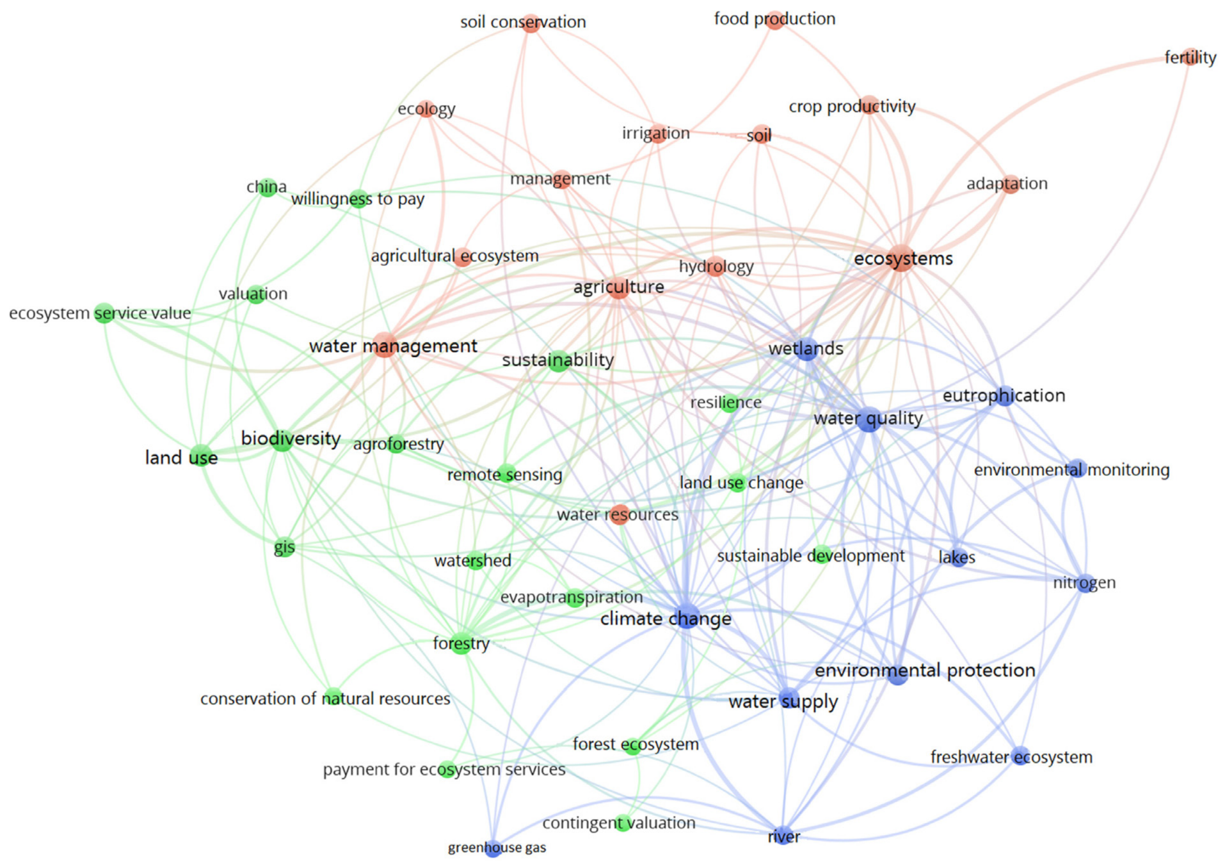

Fig. 10. Mean keywords' co-occurrence network.

disciplines to encompass an integrative analysis of the set of services that contribute to ensure ecosystem sustainability, which includes value assessments at different regional scales and considers the synergies and trade-offs between services, management systems and different ecosystems.

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